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GASFREEING OF CARGO TANKS

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GASFREEING OF CARGO TANKS[1]

by

M. G. Zabetakis[2]

SUMMARY AND INTRODUCTION

The process of "gasfreeing" has been defined[3] as "* * * the removal of oil and vapors from tanks, pipelines, and compartments to render such spaces safe for the intended work." Generally, part or all of a vessel is gasfreed for one of several reasons: Periodic cleaning; tank inspection or repairs; shipyard overhaul or major repairs; or change of cargo. During the gasfreeing, flammable or explosive[4] mixtures (mixtures through which a flame can propagate after ignition by an open flame, heated object, electrical charge, or other means) may be produced. These mixtures create an explosion hazard, as the pressures produced after their ignition are often great enough to completely demolish the vessel and kill all those aboard. This paper outlines a study by the Federal Bureau of Mines of the gas explosion hazards likely to be encountered while gasfreeing a vessel compartment. To better understand these hazards it will first be necessary to review the language used in gas-explosions work. This language is considered in the following sections.

Inert gases such as carbon dioxide, nitrogen, water vapor, and others can be used to decrease the range of combustible-vapor concentrations in which flammable mixtures are formed. Sufficient quantities of such gases can often be added to cause a mixture that originally was flammable to become nonflammable . Unfortunately, the use of water vapor in this application is complicated by the fact that elevated temperatures are required to keep the water in the vapor state. In practice, it may be difficult to maintain these elevated temperatures throughout the space (such as a cargo tank) to be inerted for any length of time. Accordingly, where other inert gases are not available, it may be desirable to gasfree a tank by using heated air. To do this, the combustible vapors should be flushed as quickly as possible from the space to be gasfreed. In a properly designed system, large tanks were gasfreed with a littlee as 6 volumes of air per volume of tank capacity.

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[3] NAVSHIPS 250-341 (MSTS P-105), September 1950, p. 9.

[4] Flammable and explosive are used interchangeably here.

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FLAMMABILITY DIAGRAMS

Ordinary fuels such as gasoline, oil, and aviation jet fuel are flammable only when vaporized and mixed with air or other oxidants, such as oxygen, nitric acid, and chlorine, over a definite range of mixture compositions. As the bulk storage and transport of such fuels are of primary interest, only applications in which air, or more accurately the oxygen in the air, is the oxidant will be considered. For example, gasoline vapor forms flammable mixtures with air at 70° F. if the concentration of gasoline vapor is about 1.4 to 7.6 volume-percent.[5] In other words, 100 cubic feet of a gasoline vapor-air mixture is flammable if it contains 1.4 to 7.6 cubic feet of gasoline vapor, the remainder (98.6 to 92.4 cubic feet) is air. The lower value (1.4 volume-percent) is known as the lower limit of flammability or lower limit, and the higher value (7.6 volume-percent) as the upper limit of flammability or upper limit.

If inert gases such as carbon dioxide, nitrogen, and water vapor are added to these gasoline vapor-air mixtures, the limits of flammability are altered. In short, the range of gasoline-vapor concentrations over which flammable mixtures are formed can be effectively decreased by adding inert gas. Furthermore, the maximum explosion pressures developed by the ignition of such mixtures is reduced as the concentration of inert gas is increased. If enough inert gas is used, flammable mixtures will not be formed. In practice, when water vapor was used as the inert, elevated temperatures were required to produce enough water vapor to yield nonflammable mixtures. In addition, as mixture temperatures were raised, the range of flammable mixtures increased; that is, the lower limit decreased and the upper limit increased. These effects are illustrated in the flammability diagram in figure 1, which shows the effect of water vapor on the limits of flammability of gasoline vapor at 70° and 212° F. The gasoline-vapor concentration of any particular mixture in figure 1 is obtained by moving along a horizontal from the composition point representing that mixture to the scale on the left. For example, the gasoline-vapor concentration of a mixture represented by point A (flammable mixture) is 5.0 volume-percent. The concentration of water vapor is obtained by moving along a vertical from the composition point to the scale immediately below the "Flammable Mixtures" area; mixture A contains 12 volume-percent water vapor. Finally, if the gasoline-vapor and the water-vapor concentrations are subtracted from 100 percent, the concentration of air in the mixture is obtained. Mixture A therefore contains 100-5-12 or 83 volume-percent air. As a second example, notice that mixture B (nonflammable mixture) contains 6.5 volume-percent gasoline vapor, 20 volume-percent water vapor, and 100-6.5-20 or 73.5 volume-percent air.

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[5] These values may vary somewhat from one gasoline to another, but they are representative of a variety of gasolines available today.

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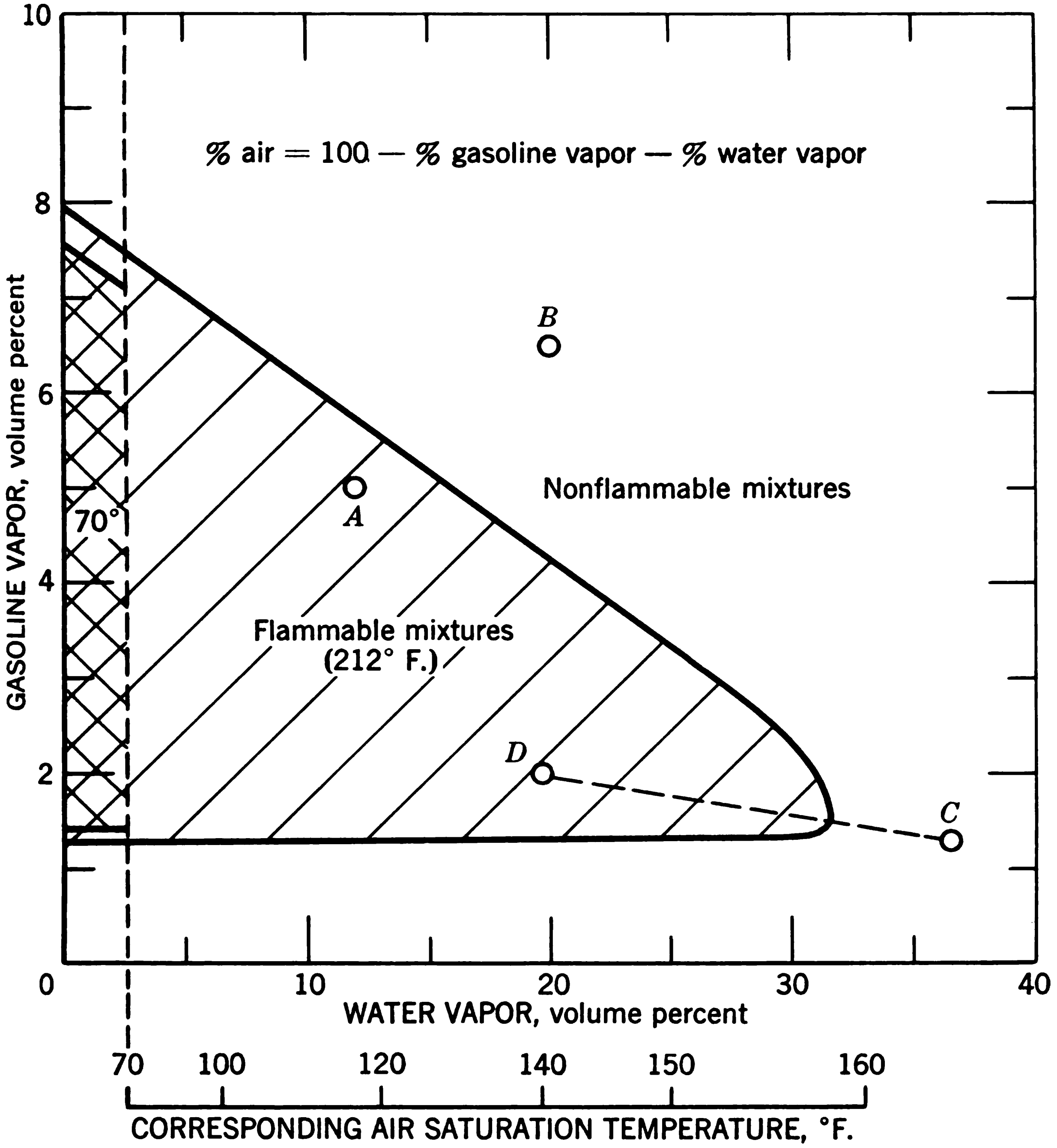

FIGURE 1. - Flammability Diagram for the System Gasoline Vapor-Water Vapor-Air at 70° and at 212° F. and Atmospheric Pressure.

Thus far, the air-saturation temperature scale included under the water-vapor concentration scale in figure 1 has not been considered. This scale is fairly straightforward. It shows the temperature required to obtain a particular water-vapor content when the mixture is saturated with water vapor at

1 atmosphere. For example, a gasoline vapor-water vapor-air mixture at 70° F. can contain a maximum of 2.5-percent water vapor, and at 125° F. such a mixture can contain 13.5 percent water vapor. In practice, any water-vapor content between zero volume-percent and the saturation value (for example, 2.5 percent at 70° F., 13.5 percent at 125° F.) can be found in a mixture, depending on the degree of saturation of the mixture under consideration. In a particular instance, the saturation value or maximum water vapor content of a mixture can be increased only by elevating its temperature (and introducing more water) or by decreasing the pressure. Since only applications at atmospheric pressure are under discussion, the possibility of pressure decrease will not be considered. Accordingly, the maximum water-vapor content depends only on the mixture temperature.[6] If any gasoline vapor-air mixture is saturated with water vapor at a temperature of at least 160° F., it will be nonflammable; however, if it is permitted to cool to a lower temperature, such as 125° F., the water-vapor concentration will fall and in some instances will produce flammable mixtures. For example, mixture C (fig. 1) is nonflammable at 164° F.; however, if the temperature falls to 140° F., all compositions between C and D are formed. Eventually, the entire mixture reaches the composition represented by point D, which is in the flammable (and saturated) area at 140° F.

To use a flammability diagram such as figure 1 effectively, the significance of the flammable-mixtures area, saturation temperature, and other factors must first be known. Besides, as changing mixture compositions are often encountered, the way in which a change in water vapor, gasoline vapor, or air content affects the location of the mixture composition point on the flammability diagram must be known. Figure 2 shows the direction of shift of composition point A when water is added (plus water vapor) or removed (minus water vapor), air is added (plus air) or removed (minus air), and gasoline vapor is added (plus gasoline vapor) or removed (minus gasoline vapor). The scales used in figure 1 were decreased to permit the complete flammability diagram to be drawn as a single graph. This diagram is not too practicable, however, as the flammable-mixtures area "Flammable" is reduced so much that it is difficult to use for precise work. Nevertheless, the figure is useful in that it helps in visualizing the effects of changes in mixture compositions. Briefly, if water vapor is added to a mixture, all mixture compositions between the original one, such as A, and pure water vapor will be formed, and the composition point shifts towards the 100-percent water-vapor point, as already noted. If water vapor is removed by condensation or absorbtion, the composition point moves along the extension to the line drawn from A to the 100 percent water-vapor point but in the opposite direction to that in which water vapor was added; that is, it moves away from the 100-percent water-vapor point. The same applies to the other constituents, air and gasoline. If more than one constituent is involved, the final composition point can be found by considering one constituent at a time. With this background in mind a few applications can be considered. For these, a new flammability diagram (fig. 3) has been constructed.

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[6] Fine water mists would also tend to give an inerting effect; however, since these eventually fall out of the space being inerted they are not considered.

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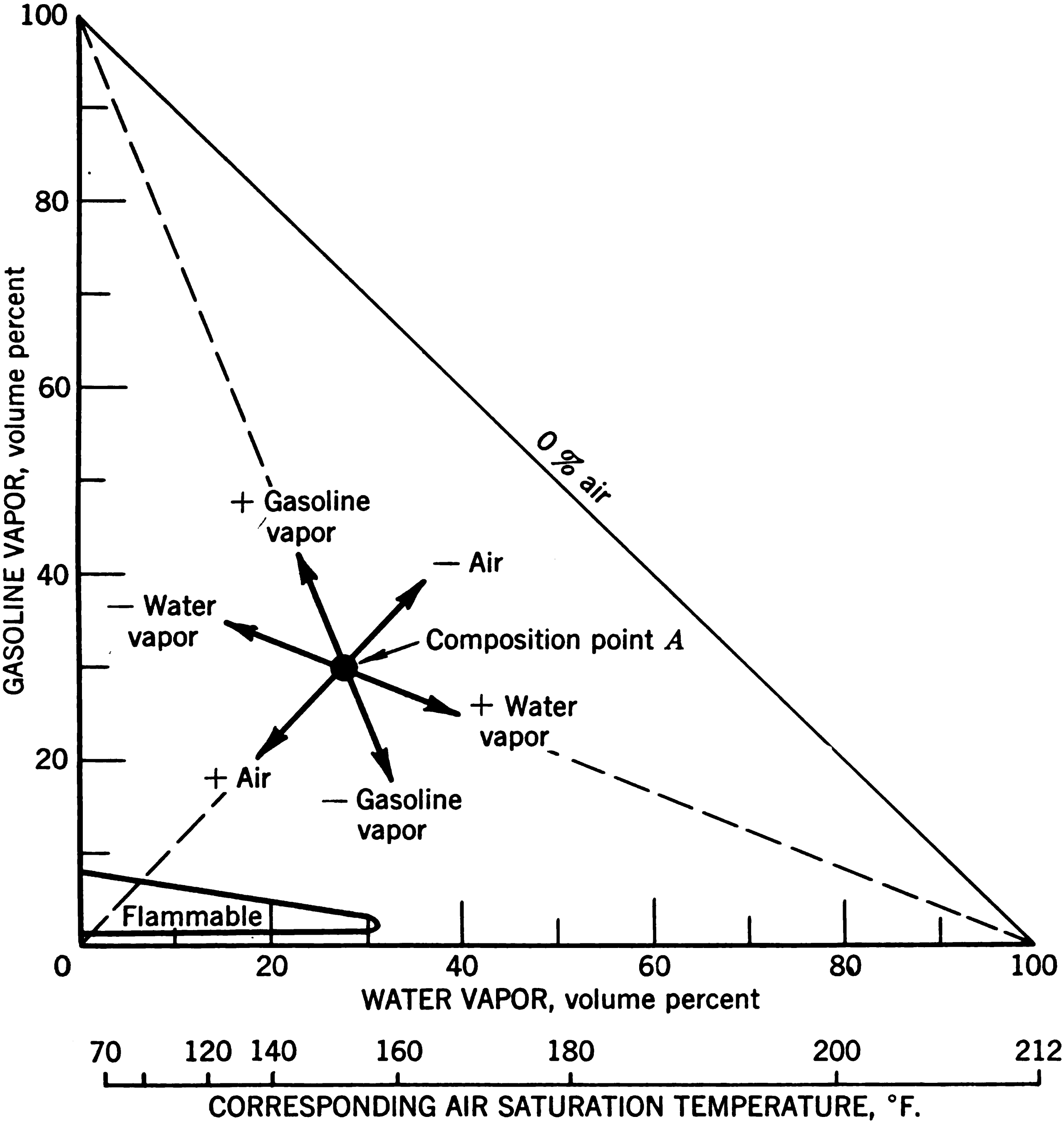

FIGURE 2. - Flammability Diagram for the System Gasoline Vapor-Water Vapor-Air at 212° F. and Atmospheric Pressure Showing Direction of Shift in Composition Point with Variation in Mixture Composition.

APPLICATIONS

Consider a saturated gasoline vapor-water vapor-air mixture in a tank at 70° F. Such a mixture is represented by composition point A in figure 3.

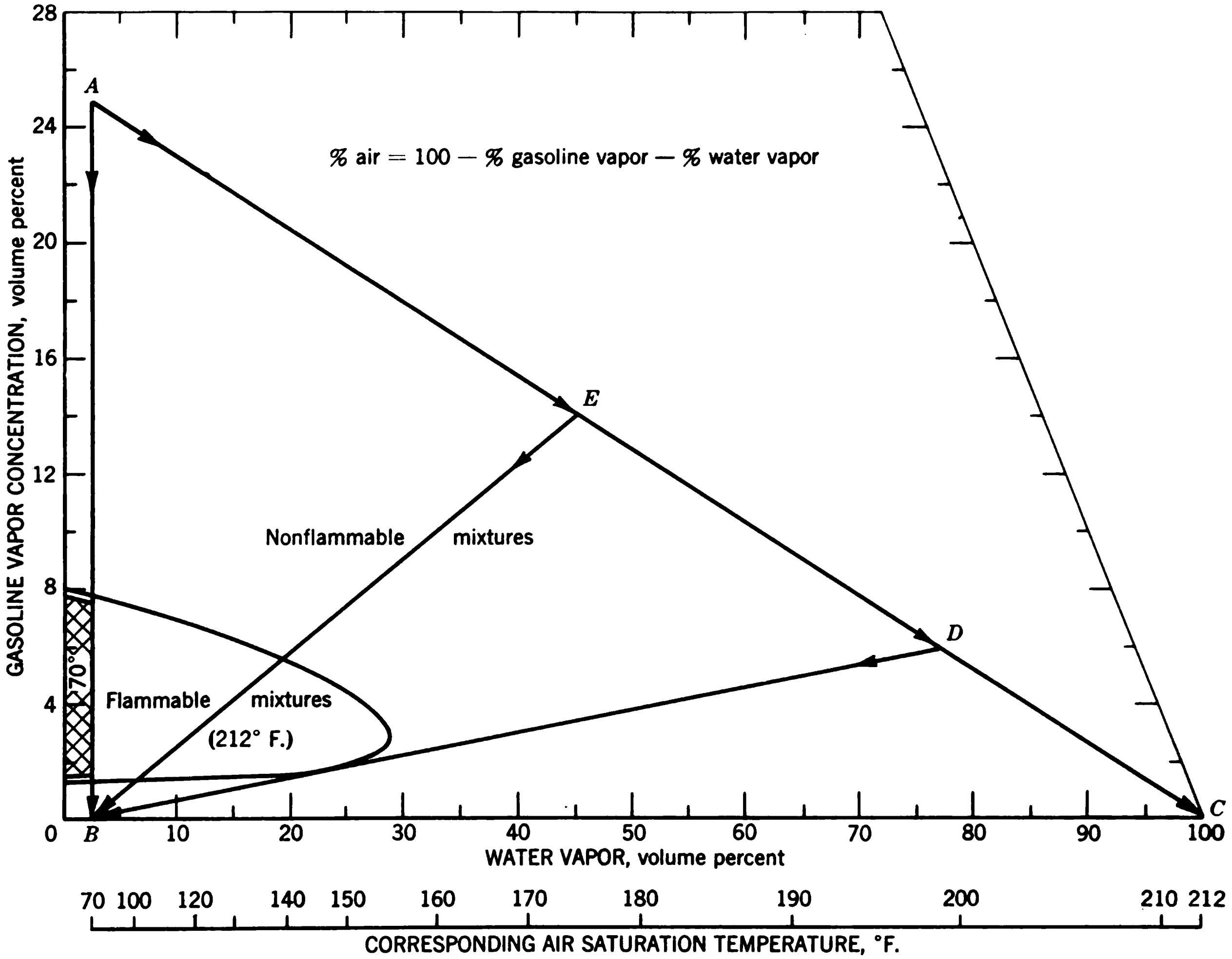

FIGURE 3. - Flammability Diagram for the System Gasoline Vapor-Water Vapor-Air at 70° and at 212° F. and Atmospheric Pressure.

A more volatile gasoline than that considered here would yield a mixture containing more gasoline vapor, and a less volatile one would yield a mixture containing less gasoline vapor. However, the composition point shown here is fairly typical. If the mixture is diluted with air saturated with water vapor at 70° F., all compositions between A and B will be formed until all the gasoline vapor is flushed from the tank, and mixture B alone (air saturated with water vapor) remains. On the other hand, if steam (water vapor) is used to dilute mixture A, all compositions between A and C will be formed until all the gasoline is flushed from the tank and steam alone remains (point C). Air and steam represent two extremes of the flammability diagram.

Next, the effect of using hot water and water vapor at some temperature below 212° F. should be considered. In considering the results to be expected when water at 175° F. is used, if air is not permitted to enter the tank the mixture composition can be readily shifted to point E. In a constant-volume tank at atmospheric pressure, this shift would be accompanied by expulsion of the mixture from the tank. All mixture compositions between A and E would be expelled if the water vapor mixed fairly rapidly. The expelled mixtures would combine with air outside the tank and yield mixture compositions between those originally expelled and that represented by point B; in some instances, the composition of the expelled mixture would shift from the 100-percent water-vapor point because of condensation of the water-vapor outside the tank. In any event, the mixture within the tank would remain at E unless air was used to flush the tank, in which case mixture compositions between E and B would then be formed. Again, if water vapor condensed within the tank, the mixture composition would be shifted from the 100-percent water-vapor point toward A. Nevertheless, addition of air to the mixtures in the tank would result in the formation of flammable mixtures. Only if water vapor were added near 205° F. and the water vapor did not condense (a rather unlikely situation) would flammable mixtures not be formed upon addition of the air.

Thus, it is evident that mixture A can be flushed from the tank without forming flammable mixtures within the tank only if steam or other inert gas is used. Where these are not used, it generally is desirable to flush the tank as quickly as possible, thus keeping it filled or partly filled with a flammable mixture for as short a time as possible. Tests conducted by the Bureau of Mines in a 1,000-cubic-foot tank showed that certain inlet and outlet vent locations were more efficient than others in this respect. Figure 4 gives the time required to reduce the concentration of gasoline vapor in the above tank from 20 volume-percent to the upper and lower limits of flammability with 2,000 c.f.m. of heated air introduced at the top of the tank; the tank was vented near the bottom. The flammability of the mixtures in the tank at the 1-, 5-, and 8-foot levels was determined during gasfreeing by passing a high-voltage spark through gaps at each of these three levels. The presence of a flammable mixture at the level at which a spark was passed resulted in igniting the mixture, a rapid pressure rise within the tank, and the appearance of flame through the opening produced by the rupture of a relief diaphragm. Figure 5 gives additional data for other inlet and outlet vent locations. The upper limit was reached in approximately one-half to three-quarters of a minute in each instance; the lower limit was reached at various times as noted by the curves to the right of the "Flammable" area. These data were then used to determine variations in the flammable volume within the tank with time for the various inlet and outlet vent locations. Figure 6 gives the resultant graphs.

The effectiveness of the various inlet and outlet vents used in these tests can be assessed more readily if determination is made of the quantity of air required to flush the 1,000-cubic-foot tank in each instance. This can be done easily if the time required to reach the lower limit of flammability at the bottom of each tank is multiplied by the airflow rate (2,000 c.f.m.). For example, the most efficient method required approximately 3-1/2 minutes to flush the tank until it contained mixtures below the lower limit of flammability throughout its volume. In 3-1/2 minutes 7,000 cubic feet of air was used, or 7 cubic feet of air per cubic foot of tank volume. The least efficient method required 17,000 cubic feet of air, or 17 cubic feet of air per cubic foot of tank volume. It is interesting to note that in

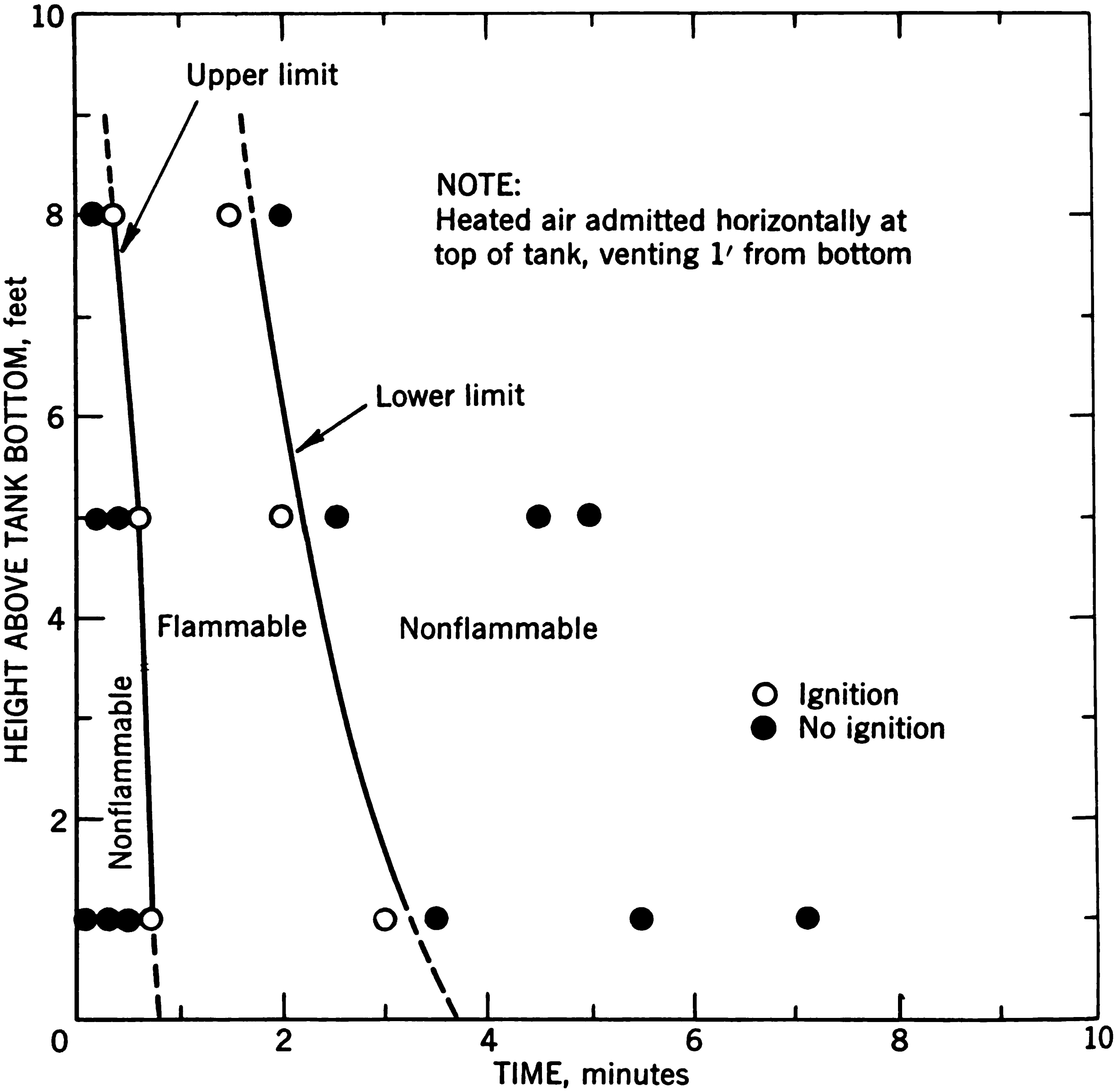

FIGURE 4. - Time Required to Reduce the Concentration of Gasoline Vapor in Air at Various Heights in a 1,000 Ft.^{3} Cubical Test Tank from 20 Volume Percent to the Upper and Lower Limits of Flammability by Forced Convection of 2,000 c.f.m. of Heated Air.

full-scale gasfreeing tests conducted aboard tankers with heated air, large cargo tanks have been effectively gasfreed by using 6 to 8 cubic feet of air per cubic foot of tank volume.

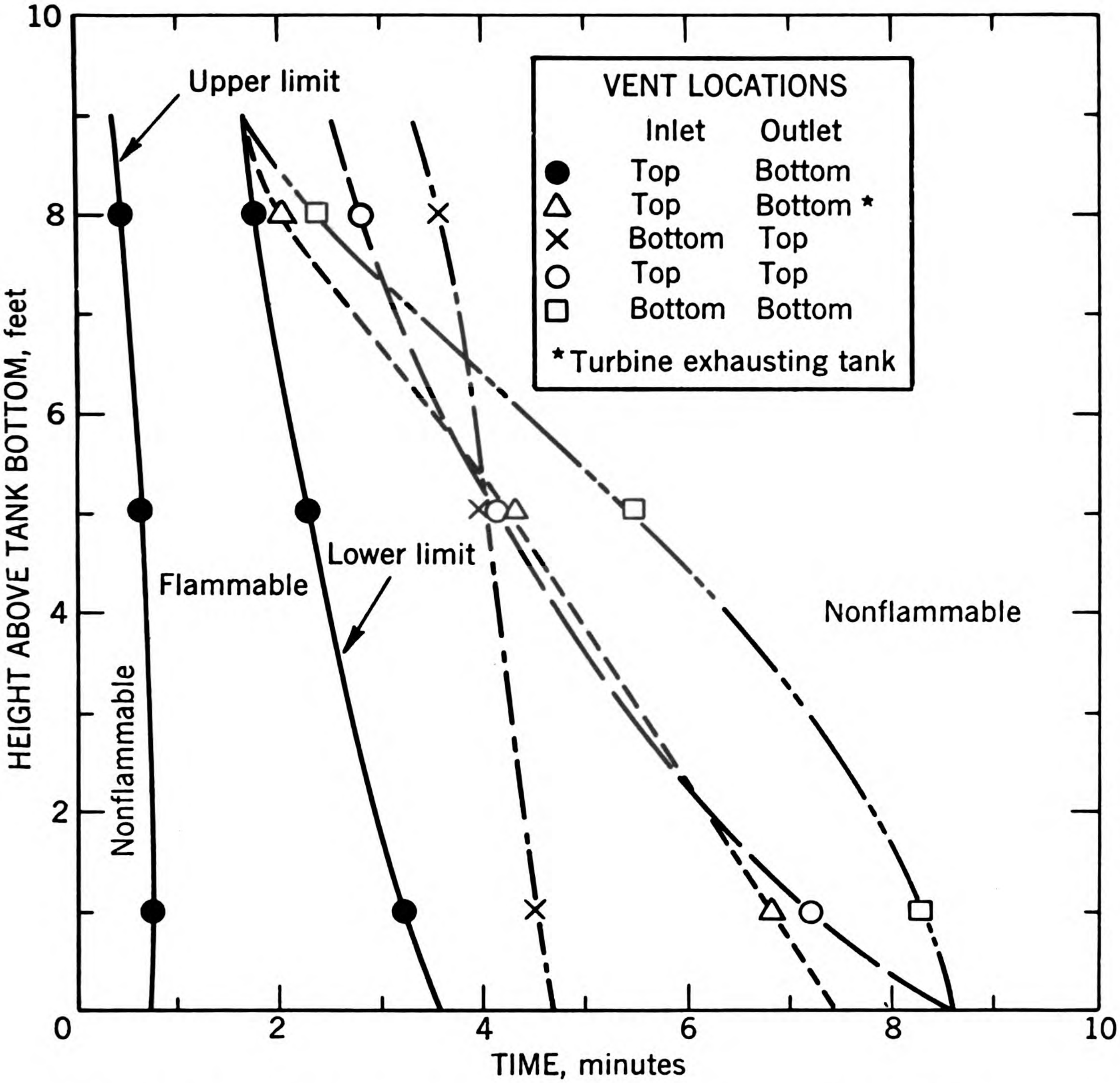

FIGURE 5. - Time Required to Reduce the Concentration of Gasoline Vapor in Air at Various Heights in a 1,000 Ft.^{3} Cubical Test Tank from 20 Volume Percent to the Upper and Lower Limits of Flammability by Forced Convection of 2,000 c.f.m. of Air.

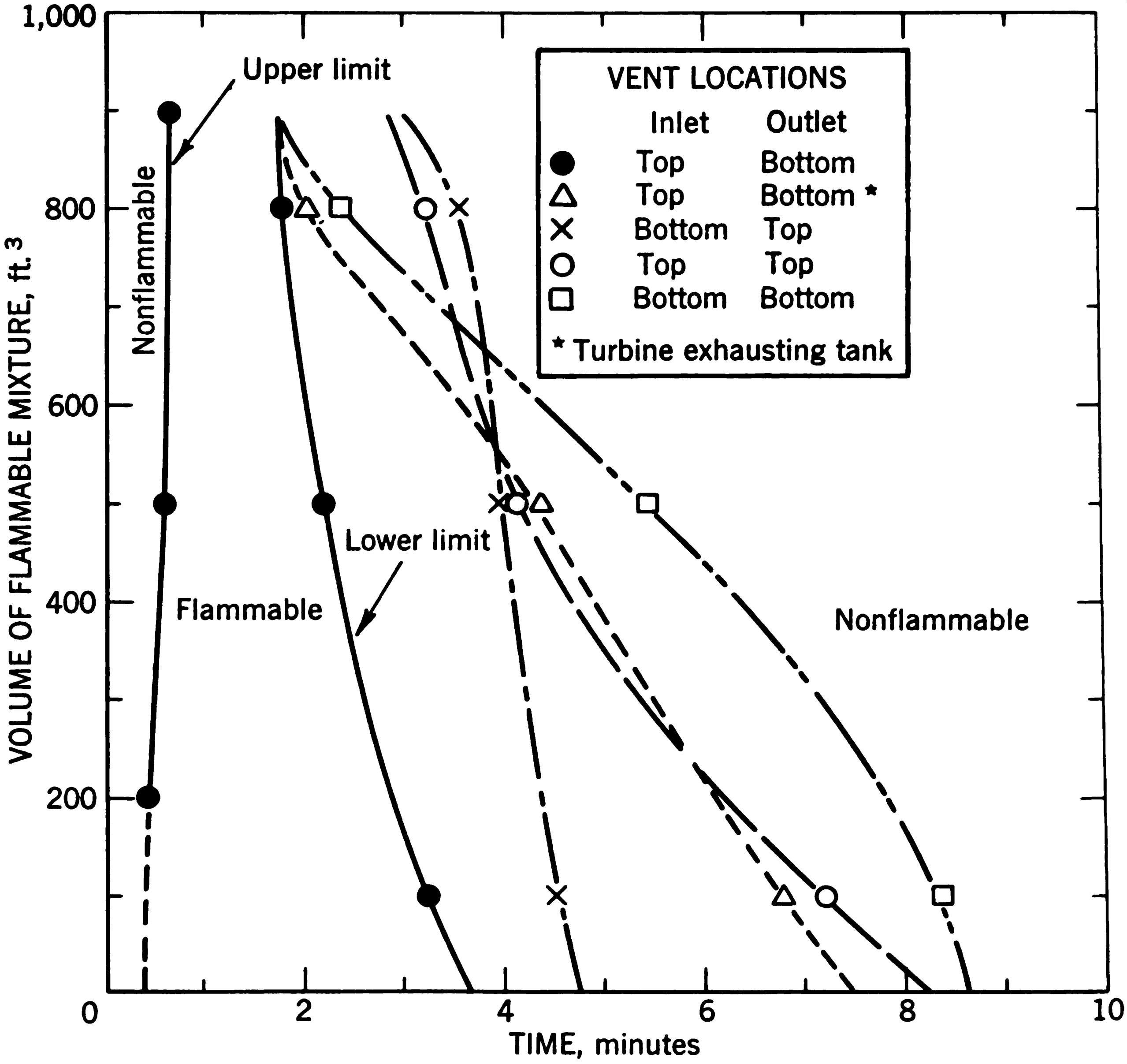

FIGURE 6. - Variation of Volume of Flammable Gasoline Vapor-Air Mixture with Time in a 1,000 Ft.^{3} Cubical Test Tank During a Gas-Freeing Operation Using Forced Convection of 2,000 c.f.m. of Air.

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